SUMMARIES OF PRE-CAMBRIAN LITERATURE OF NORTH AMERICA FOR 1909, 1910, 1911, AND PART OF 1912

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III. LAKE SUPERIOR REGION AND ISOLATED PRE-CAMBRIAN AREAS OF THE MISSISSIPPI VALLEY

Adams[1] states that the formations of the Cuyuna iron-bearing district of the north-central part of Minnesota consists of a series of complexly folded Upper Huronian slates and other clastics interstratified with lenses of iron formation, and intruded by basic Keweenawan rocks; the whole trunkated and almost completely covered by patches of Cretaceous conglomerate and a thick mantle of glacial drift, presenting a surface of gentle relief.

The iron formation occurs as a series of parallel and overlapping lenses or belts, generally associated with magnetic attraction on the limbs of trunkated anticlines, trending northeast-southwest. It presents all gradations between original cherty iron carbonates, and its secondary phases, ferruginous cherts, hard, soft, low-grade hematite ores, and amphibole magnetite rocks.

Adams follows Van Hise and Leith in his belief that the ores occur in places which have been favorable to the circulation of surface solutions, such as in inclined basins formed by pitching folds superimposed on the major anticlines or by the intersection of dikes with the walls adjacent to the iron formation lenses. Since the ores in such localities grade into ferruginous cherts, and cherty iron carbonates where the circulation of solutions was less favorable, he concludes that the ores have resulted from the oxidation of the cherty iron carbonates to ferruginous cherts and from the latter by the leaching of the silica. The amphibole magnetite rocks probably have developed from the anamorphism of cherty iron carbonates.

[1] Francis S. Adams, "The Iron Formation of the Cuyuna Range," *Econ. Geol.*, V, No. 8 (1910), 729–40; *ibid.*, VI, No. 1 (1911), 60–70; *ibid.*, VI, No. 2 (1911), 156–80.

Allen[1] reports that the stratigraphic succession in the Iron River district of Michigan from the Brule river northward consists of fine-grained, ellipsoidal basalts, and green schists probably Keewatin; Lower Huronian cherty and slaty dolomite, quartzite, and slates; Upper Huronian slates and graywackes, containing iron formation lenses in at least four horizons, and associated with basic igneous rocks, mainly extrusive. Unconformities between the major units are inferred but not known, owing to the drift-covered condition of the contacts.

The rocks are complexly folded, but the details of the structure are obscure. The major axis of folding is northwest-southeast in the eastern part of the district, east and west in the central portion, and southwest to northeast, farther west.

The Upper Huronian is divisible into three main belts or stratigraphic horizons running parallel to the major structure, that near the Brule River on the south being the lowest. The southern belt consists dominantly of slates and iron formation lenses, the productive portion of the district. The next overlying belt is ill defined, consisting dominantly of extrusive greenstones. The uppermost belt, lying farthest north, consists of slates, graywackes, basic extrusives, and iron formations.

The iron formations comprise slaty and cherty iron carbonates, ferruginous cherts and slates, magnetic, chloritic, sideritic slates, altered greenalite, and secondary soft, hydrated hematite ores. The ore bodies occur mainly as irregular sheetlike masses parallel to the bedding or as pockets related to structural basins. They are bounded by phases of lean iron formation, extrusive basic rocks, or carbonaceous shale, or any combination of these.

Buckley[2] confirms Haworth's conclusions that the pre-Cambrian rocks of Missouri consist of contemporaneous granites and rhyolites intruded by diabase dikes. About 200 feet of slate and conglomerate are exposed on Pilot Knob. The igneous rocks are correlated by Buckley with the Laurentian and the sediments with the Huronian, but the reasons for this correlation are not evident.

[1] R. C. Allen, "The Iron River Iron-bearing District of Michigan," *Mich. Geol. and Biol. Surv.*, 1910, 144 pp., 17 pls., 18 figs.

[2] E. R. Buckley, "Geology of the Disseminated Lead Deposits of St. François and Washington Counties, Missouri," *Missouri Bur. Geol. and Mines*, IX (1908), Pt. 1, 259 pp., 39 pls., 10 figs.

Crane[1] describes the pre-Cambrian iron ores of Iron Mountain, Missouri, as veins of specular hematite containing apatite and tremolite, which occur in porphyry; and detrital ores derived from the vein ores. The ores of Shepherd Mountain near by are also vein ores, but their principal constituent is non-titaniferous magnetite, with pyrite and a little clay. The Pilot Knob ores are soft blue, banded hematites, locally with ripple marks, and rest conformably on a nearly smooth floor of porphyry, and grade laterally into a porphyry breccia. The formation is separated into two parts by a claylike bed. The ore above the claylike bed is more distinctly stratified and grades upward into a hundred feet of breccia.

Crane concludes that these ores represent replaced tuffs, from the fact that they grade into breccias both along the strike and the dip. It has been found extremely difficult to explain the origin of the Pilot Knob ores under any hypothesis offered thus far. This is due in large part to the fact that only a small remnant of the ores, and the rocks associated with them have been left by erosion. The principal objection to the replacement hypothesis is found in the interstratification of non-iron-bearing materials with the ores. Under the replacement hypothesis it would be necessary to assume that the replacement of certain layers was accomplished, while others remained unaltered.

Crane does not correlate the pre-Cambrian rocks of Missouri with certain Lake Superior pre-Cambrian rocks, as some of his predecessors have done.

Grout[2] infers from analyses of Keweenawan diabase in different stages of alteration that the fresh rocks contain more copper than the altered, the copper being in the form of a basic silicate in the fresh rock, and that the more basic diabases originally contain more copper than the more acid types.

Grout[3] finds that chemical and mineralogical analyses of the Keweenawan lavas of the Kettle River region of Minnesota indicate

[1] G. W. Crane, "Iron Ores," *Missouri Bur. Geol. and Mines*, Vol. X, (1912) pp. 36–39, 107–44.

[2] Frank F. Grout, "Keweenawan Copper Deposits," V, No. 5 (1910), 471–76.

[3] F. F. Grout, "Contribution to the Petrography of the Keweenawan. *Jour. Geol.*, XVIII, No. 7 (1910), 633–57.

a close magmatic relationship between them and ascribes the differences to differentiation.

Analyses of fresh lavas containing 0.01 to 0.03 per cent of copper are cited by him as proof that the Keweenawan ores were derived from the lavas. This conclusion is open to the objection that a similar content of copper has been found in many rocks where no ores were developed.

Lane[1] finds that the waters from the deep levels of Michigan iron mines are high in sulphates and chlorides which are associated with calcium rather than sodium. The carbonate radical is low and decreases with depth. Their silica content is like that of ordinary cold surface waters, and they contain almost no iron.

A. C. Lane and A. E. Seaman[2] divide the pre-Ordovician of Michigan into Keewatin, Huronian, and Cambrian or Primordial. The Keewatin corresponds to the Archaean; the Huronian to the Algonkian; and the Cambrian or Primordial to the Keweenawan and Potsdam of Van Hise and Leith. Lane believes that the Potsdam and Keweenawan should not be placed in different geologic periods because of their stratigraphic and structural similarity and continuity, and because no unconformity can be found between them.

Lane[3] recognizes the following groups of Upper Michigan Keweenawan rocks from the base upward: (1) Bohemian Range group: consisting mainly of basic lavas but with intrusive and and effusive felsites and coarse labradorite porphorites; also intrusive diabase dikes and gabbro aplites, with a total thickness of about 9,500 feet; (2) the central mine group: mainly lavas of an augitic ophite type with infrequent sediments; this includes the Allouez conglomerate, the Calumet and Hecla conglomerate, and the Kearsarge lode; the total thickness is placed at from 3,823 to 25,000 feet; (3) the Ashbed group: consisting of basic lavas of the

[1] A. C. Lane, "Michigan Iron Mines and Their Mine Waters," *Jour. Can. Min. Inst.*, XII (1909), 114–29.

[2] Notes on the Geological Section of Michigan," part of *Annual Report* for 1908, Michigan Geological Survey, 1909, 120 pp.

[3] A. C. Lane, "The Keweenawan Series of Michigan," *Mich. Geol. and Biol. Surv.*, 1909, 2 vols., 932 pp.

Ashbed type with scoriaceous sediments and a little conglomerate. The thickness may be between 1,456 and 2,400 feet; (4) the Eagle River group: a group of basic lava flows with frequent beds of sediments; its thickness is between 1,417 and 2,300 feet; (5) the Great Copper Harbor conglomerate: a coarse, heavy conglomerate from 1,800 to 2,200 feet thick; (6) the Lake Shore traps: a series of thin flows having a total thickness of about 800 feet; (7) the Outer Copper Harbor conglomerate: from 1,000 to 5,000 feet in thickness; (8) the Nonesuch shales: black, fine-grained, micaceous sands and grits, about 500 feet in thickness; (9) the Freda sandstones: red, impure sands, shales, and conglomerates; 4,000 or more feet in thickness.

The Keweenaw rocks dip at a high angle toward the north under Lake Superior and in general strike parallel to the axis of the Keweenawan Peninsula. They have also been disordered by numerous faults. The great Keweenaw fault, a longitudinal fault dipping toward Lake Superior and cutting across the bedding, is regarded by Lane as a thrust fault due either to the contraction of the earth's crust or to uplift produced by the injection of a large sill. Movement along this fault began before Cambrian time and has taken place since the deposition of the Niagara limestone. There are also other faults both parallel to the bedding and longitudinal faults which cut across the bedding. There are numerous vertical or nearly vertical transverse faults which have produced an offset of the beds to the right in going toward the northeast.

The Keweenaw rocks of northern Michigan as well as those of other parts of the Lake Superior region show strong evidence of consanguinity. Thus in all of these rocks potassa appears to be subordinate to soda except in extremely siliceous varieties, and in general the potass is very low. Free quartz is not abundant. There is never an excess of alumina which would result in the development of corundum nor are there any ultra-alkaline or ultra-basic rocks. The content of iron is decidedly high. According to Iddings' classification, the commonest type would be auverngnose. No rocks are known which contain less of both silica and alkalies.

Lane finds that the composition of these rocks is on the sodic side of a line which he regards as a hypothetical eutectic between

alkalies and silica. In harmony with this, he finds very few cases of porphyritic texture and very little difference in the time of crystallization of the various constituents. In general, labradorite has come out first and augite last in the dikes and flows, while in the deep-seated intrusives, the order is reversed. He also regards the development of olivine rather than enstatite or hypersthene as in harmony with the position of the analyses with respect to his hypothetical eutectic.

The igneous rocks are all crystalline. If any glass has existed in these rocks it has long since become devitrified. The following varieties of texture are described by Lane: (1) ophitic, in which the augite crystals occur as a cement, enclosing idiomorphic feldspars; this texture characterizes the central portion of the basic effusives; (2) doleritic texture, in which the feldspar is much coarser than the augite; (3) glomeroporphyritic or navitic, in which the feldspars present a great range of size and tend to aggregate in bunches; (4) porphyritic hiatal, characterized by coarse feldspar phenocrysts imbedded in a ground mass in which the feldspars are very small; (5) amygdaloidal texture in which blow holes have resulted from the escape of gases; (6) microlitic, a texture which develops around amygdules; it is characterized by fine slender prisms of feldspars; (7) vitrophyric, consisting of a glasslike ground mass in which a few crystals are imbedded; it is always found within a few millimeters from the margin; (8) the graphic texture, consisting of intergrowths of quartz and feldspar; it is very common in the interstices of the Bessemer gabbro and is also very abundant in felsite conglomerate pebbles; (9) spherulitic texture, found only in salic rocks; it is characterized by small spherules of rock; (10) mozaic texture, consisting of equigranular quartz and feldspar.

The factors which determine the grain of igneous rocks are stated by Lane to be the chemical composition, temperature, and pressure of the magma. He presents a mathematical discussion of the relation between grain and cooling.

The mean annual temperature of the air on Keweenaw Point is between 38° and 42° Fahrenheit. The temperature of the upper mine levels at a depth of from 100 to 236 feet varied from 43° to 50°, and the average was nearly 43°. The rate of increase of

temperature with depth is found to be very small, about 1° in 103 feet. Lane suggests that this low temperature gradient may be due to chemical reactions which absorb heat, such as the deposition of copper; the diffusivity of the strata, permitting the early and free escape of heat; downward absorption of water carrying with them cooler temperatures of the surface; recent deposition of surface drift, and the relative exhaustion of the internal supply of heat by the Keweenaw and earlier eruptions.

The mine waters of the region are of three types: (1) normal surface carbonate waters, in which calcium and magnesium are in excess of sodium; (2) waters of intermediate levels, 1,000–2,000 feet, high in sodium and chlorine, in which lime and magnesium are subordinate; (3) waters of deep levels in which lime chloride dominates, and in which magnesium is absent or nearly absent and sodium subordinate. Waters of type (2) are associated with the richest part of the lodes and with the occurrence of silver. The deep waters are regarded by Lane as connate waters, but not necessarily derived from the ocean of that time.

Lane regards the lavas and sediments as the original source of the copper. All the lavas and sediments contain at least 0.02 per cent or more of primary copper. The lavas and sediments he believes were deposited rapidly one upon the other, the lavas retaining their heat for a long period of time. Water and gases containing chlorine were given off by these lavas and these caused a hydration of the silicates of the rock, developing chlorite and epidote and some native copper. This first alteration, however, he believes was insufficient to account for the development of all the copper, since the occurrence of the copper in the porous parts of the formation indicates that circulation of water must have taken place. The circulation which Lane believes developed the ores was set up largely through the cooling of the rocks. As the rocks cooled they contracted and afforded openings for water which was sucked in from the surface. A large part of this water entered into chemical combinations with the rocks and thus a very strong and long-continued downward circulation must have been set up, since the greater portion of the rocks have been hydrated to chlorite. This reaction also involved solution of sodium silicate, copper, and lime

in the form of chloride. The precipitation of the copper Lane believes took place according to the experimental results of Fernekes, the copper being taken out of solution by means of ferrous chloride in the presence of alkalies, principally in the form of calcite and prehnite and datolite, since the copper shows most intimate associations with these minerals.

Paige[1] states that the pre-Cambrian rocks of the Llano-Burnett region consist of a sedimentary series of gneisses and schists and banded iron formation lenses composed of alternating layers of magnetite, quartz, and silicates, the whole intruded by a large development of granites and minor basic igneous rocks.

Richardson[2] states that the lowest pre-Cambrian rocks of the El Paso district are white and red quartzites, fine, round grained, intruded by diabase dikes. About 1,800 feet are exposed in the Franklin Mountains. The dip of the beds is 20°–45° west. They are separated by a slight unconformity from 1,500 feet of massive red rhyolite porphyry overlying them. The rhyolite is separated by a marked unconformity from the Cambrian beds above it.

Sharwood[3] publishes a large number of analyses of the rocks, minerals, ores, and waters of the Homestake mine, as a supplement to *Professional Paper No. 20* of the U.S. Geological Survey.

Steidtmann[4] finds that a minority of the joints of the Baraboo quartzite are clearly related to the local folding; namely, joints parallel to the bedding, and strike joints which dissect the bedding. The abundance of the joints is related to the intensity of the folding. The majority of the joints are vertical, gaping, continuous cracks, which are not related to the local folding, but probably belong to larger units of structure.

Todd[5] states that the pre-Cambrian rocks have been penetrated by borings in the Aberdeen-Redfield quadrangles of South Dakota.

[1] Sidney Paige, "The Mineral Resources of the Llano-Burnett Region, Texas," *Bull. 450, U.S. Geological Survey*, 1911, pp. 103, maps and illustrations.

[2] G. B. Richardson, "The El Paso Quadrangle," *U.S. Geological Survey, Folio 166*, 1909, 11 pp., 2 pls., maps, etc.

[3] W. J. Sharwood, "Analyses of Some Rocks and Minerals from the Homestake Mine, Lead, South Dakota," *Econ. Geol.*, VI, No. 8, pp. 729–89.

[4] "The Secondary Structures of the Baraboo Quartzite," *Jour Geol.*, XVIII, No. 3 (1910), 259–70.

[5] J. E. Todd, "The Aberdeen Redfield Folio," *U.S. Geological Survey, Folio 165*, 1909, 13 pp.

They include a quartzite, believed by Todd to be the Sioux quartzite, granite, and mica schist.

F. T. Thwaites[1] concludes that the sandstones of the Wisconsin coast of Lake Superior form a single conformable series, which may be separated into two groups, which grade into each other, viz., a lower group, consisting of steeply tilted red feldspathic sandstones and fragments of igneous rocks, shales, and conglomerates; and an upper group, composed of slightly disturbed red and white quartz sandstones. The contact of the upper group with the Middle Keweenawan traps is marked by a thrust fault. A small amount of conglomerate in the sandstones along this contact may indicate a local unconformity. Since the faulting, folding, and erosion of the traps and the deposition of the sands went on simultaneously, there is no reason for believing that this conglomerate represents a great time interval, if indeed any. Irving placed the upper group in the Cambrian since he regarded the sandstone faulted against the Middle Keweenawan traps at St. Croix Falls and the same in age as the sandstone at the falls of the Amnicon River. Thwaites shows that the former is Upper Cambrian, but that the latter is older.

The conditions of deposition of the sandstones appear to have been dominantly subaerial as indicated by current marks, mud cracks, rain prints, irregular and curved bedding, depressions in shale beds filled with sands, red color, and feldspathic content.

The relations of these sandstones to the known Cambrian of Wisconsin is still doubtful. Thwaites points out certain differences between them. The Cambrian is marine as shown by fossils, and its sands generally consist of rounded, yellow quartz grains often enlarged so as to show crystal faces, and cemented dominantly with calcite. The sandstones of the Lake Superior coast lack fossils and were largely deposited under subaerial conditions. Their feldspathic content, angular grain, irregular quartz enlargements, red color, irregular and curved bedding, and lack of calcite cement contrasts strikingly with the characteristics of the known Cambrian.

Van Hise and Leith's[2] "The Geology of the Lake Superior Region" is a summary of the geology of the Lake Superior region.

[1] F. T. Thwaites, "Sandstones of the Wisconsin Coast of Lake Superior," *Wis. Geol. and Nat. Hist. Surv. Bull. 25*, 1912, pp. 109.

[2] "The Geology of the Lake Superior Region," *U.S. Geological Survey, Monograph 52*, 1911, 641 pp., 49 pls., 76 figs.

Their conclusions on the origin of the sedimentary iron formations from which the ores were derived by secondary concentration will be considered here. The unaltered iron formations consist essentially of alternating bands of chert, iron carbonate, oölitic greenalite, and iron oxides, varying in thickness from a few feet to more than a thousand feet. It is inferred that they are chemical sediments from their composition, lack of fragmental texture, and bedding. They show a great variety of lithologic associations, subaqueous ellipsoidal greenstones, tuffs, acid extrusives, and normal sediments, viz., quartzites, limestones, and slates.

From the fact that the iron content of the thick formations and the sediments associated with them is greater than the iron content of the rocks which antedate them, and since normal weathering tends to fix iron in place rather than to cause its transportation and deposition elsewhere on a large scale, it is concluded that the iron in these thick iron formations is not the result of a normal cycle of erosion, but was contributed from some unusual source. Further evidence for this conclusion consists in the fact that their thickness, composition, and structural characteristics do not resemble either the bog or the glauconite deposits of the present time. Furthermore, their calcium-magnesium ratio is the reverse of that prevailing in normal sediments. On the other hand, the small bodies of iron formation, particularly those interbedded with slates, are similar in their composition, thickness, and association to deposits formed by the solution, transportation, and deposition of iron by processes of normal weathering. The unusual source of iron as well as of the silica of the thick deposits Van Hise and Leith believe may have been from the submarine extrusions of basic lavas, with which the iron formations are more or less associated in time and in place. They postulate that the lavas may have contributed the iron solutions directly, or that iron solutions may have been formed from the interaction of the hot lava and sea water, and that the lavas may have furnished iron solutions by weathering.

They show that salt water acting on hot basalt forms sodium silicate, and that sodium silicate in the presence of iron salts will form oölitic iron silicate and silica which are thrown down in alternating bands, and that when carbonic acid gas is present, iron carbonate

may form instead of the silicate, while in the presence of abundant oxygen, the development of alternating bands of ferric oxide and silica may take place. Thus by simple laboratory reactions, the composition, textures, and structures of the Lake Superior iron formations are duplicated.

The monograph cites a number of cases of the intimate association of sedimentary iron formations of various ages with eruptive rocks in places outside of the Lake Superior region, but fails to name one of the most striking cases which presents a close parallel to that of the Lake Superior region, namely, the oölitic, banded, marine Devonian hematites of the Harz Mountains, which are intimately associated with subaqueous basalt extrusions, diabase, tuffs, and limestones.

Wright[1] discusses the relations of the ophites, oligoclase gabbro and aplite of Mount Bohemia at Lac La Belle on Keweenaw Point.

The oligoclase gabbro is intrusive into the ophite flows, but the aplite inclosed by the gabbro is regarded as a differentiate from the gabbro. The process of differentiation is supposed to have been accomplished by fractional crystallization, convection currents, and general upward movement of the lava. The intrusives contain veins of sulphides and arsenides of copper which are regarded as genetically related to the native copper deposits in higher horizons of the ophites. The contact metamorphism of the ophites by the gabbro is slight. Diopside has changed to uralitic hornblende, and there is a slight increase in silica and oxidation of iron at the contact.

[1] F. E. Wright, "The Intrusive Rocks of Mount Bohemia," part of *Ann. Rept.* for 1909, Michigan Geological Survey, 32 pp.

[*To be continued*]